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Lexan® In-Mold Films

A Guide for Designing, Forming and Molding with Screenprinted Lexan® Films

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Introduction

One of the most efficient and cost-effective ways to decorate a part is to do it during the molding cycle. In-mold decoration (IMD) is accomplished by inserting a decorated Lexan® film into the cavity of the molding tool and injecting plastic behind the film. In-mold decoration can provide several advantages over other decoration methods:

Design flexibility
- In-molded graphics can provide product differentiation for consumer applications.
- Quick changeovers of graphics can be done with the same injection molding tool.
- Complex 3D parts can be decorated.

Manufacturing productivity
- Parts can be decorated then molded in one operation.
- Processing and labor costs can be reduced.
- Secondary operations such as adhesives can be eliminated.
- The in-molded film remains in place for the life of the part.

To optimise IMD, a number of prerequisites should be considered:
- Selecting the proper Lexan film and thickness.
- Determining which surface will be decorated.
- Screenprinting the design with the part aesthetics and gating system in mind.
- For a 3D part, accessing vacuum forming or cold forming expertise.
- Knowing the OEM's specifications and requirements for the program.
- Selecting compatible film/resin/ink combinations (the company suggests using Lexan film for the film substrate and compatible engineering thermoplastics such as Lexan, Cycoloy®, Valox®, and Xenoy® resins).

This manual will explore various components of the IMD process:

Material Selection
- Film
- Resin
- Inks

Design & Tooling Considerations
- Forming
- Trimming
- Molding

Processing Considerations
- Printing
- Forming
- Molding

Markets/Applications

There are several market segments where IMD is being explored or is currently in the marketplace. The key segments are: automotive, appliance, computer/ business equipment, and telecommunications. Market drivers for these segments include:

Automotive
- Design freedom (three-dimensional graphics)
- Ergonomics and styling – interior harmony
- Integration of several components
- Cost savings
- Functional backlit parts
- Recyclability

Appliance
- Cost savings
- Scratch resistance
- Product differentiation via styling

Computer/Business Equipment
- Product differentiation
- Recyclability
- Manufacturing flexibility in design

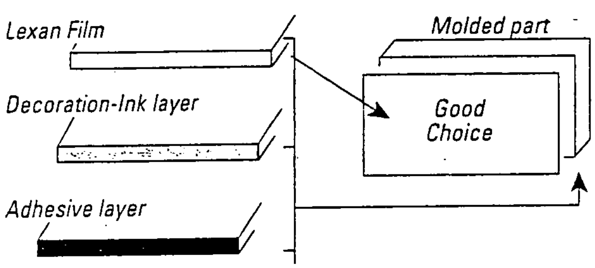
Telecommunications
- Product differentiation
- Lens integration
- Thin wall design

IMD

IMD (In-Mold Decoration) is the process by which an injection or compression molded part can be decorated during the molding cycle. IMD is also known as insert molding. Insert molding is the process in which a preformed and decorated film part is inserted into the mold cavity prior to the injection molding process.

IMD has many advantages over the traditional printed film overlay. A typical film overlay (see Fig. 1) involves the screenprinting of a film substrate (either first or second surface) and then the application of an adhesive with a protective release liner. The release liner is then removed and the film/adhesive combination is applied to the molded part.

Figure 1: Conventional Label Method



Advantages of IMD

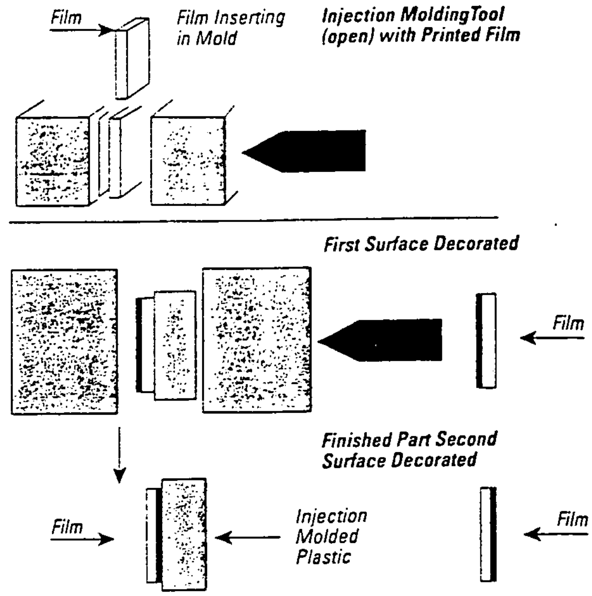
IMD has a number of obvious advantages over many traditional decorating processes. These advantages are:

- Elimination of label overlay application
- Elimination of costly and environmentally unfriendly solvent-based adhesives
- Elimination of secondary labor for overlay application
- 3-D graphic parts possible
- Remains in place for life of part
- More cost-effective method to decorate functional parts

The IMD Process

The IMD process is illustrated in Fig. 2. A description will follow of the necessary steps in the IMD process for a number of different applications. All details for each process are covered later in this manual.

Figure 2: Insert Molding Film Method

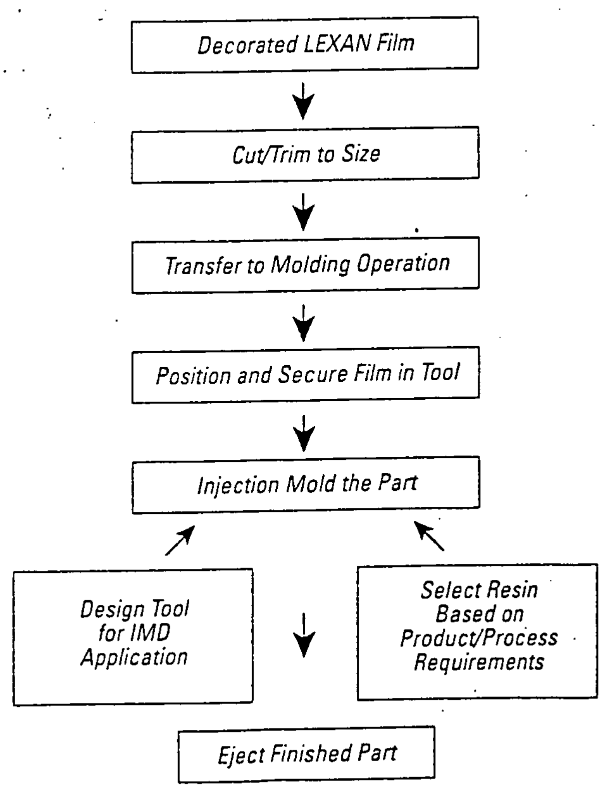


Flat Film Part/First Surface Graphics

This is the simplest IMD part to produce. A schematic diagram for constructing this type of IMD part is illustrated in Fig. 3.

Lexan film is first or second surface decorated, die-cut to size, positioned, and secured into an injection molding tool designed for IMD. Resin is then injected onto the film and a finished part, which requires little or no secondary operations, is ejected.

Figure 3: IMD Process: Flat Film Part/First or Second Surface Graphics



Flat Film Part/ Second Surface Graphics

This part is similar to the flat part with first surface graphics, however, the graphics are now screenprinted on the back or second surface of the film. This type of part provides the ability to protect the graphics during the life of the part. A schematic diagram of the IMD process for producing this type of part would be similar to the one in Fig. 3. Notable differences between the previous process are that more robust ink systems must be used, and that the gating and resin choices in the injection molding process require special consideration.

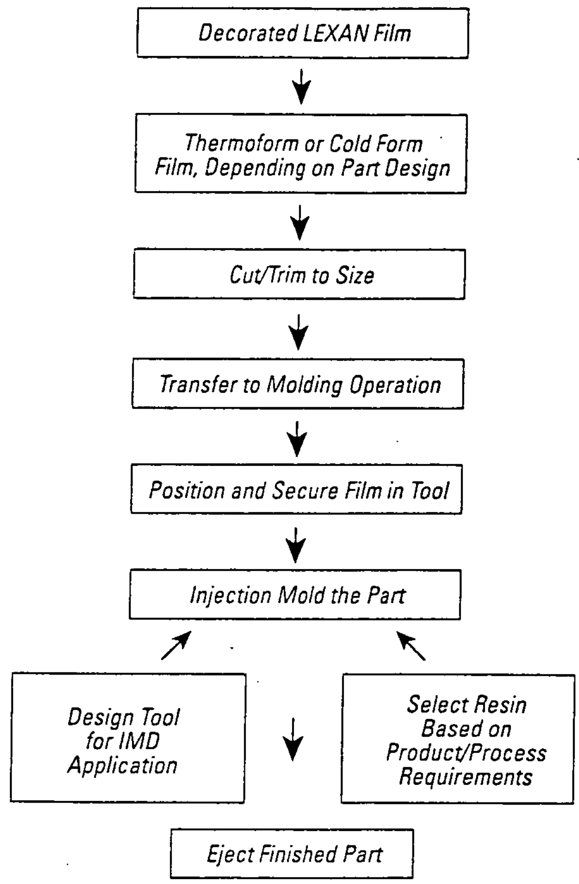
Curved Film Part/ First Surface Graphics

This part is a little more challenging, since the film must be preformed before insertion into the injection molding tool. A schematic diagram to construct this type of IMD part is illustrated in Fig. 4. Lexan film is first surface decorated (screenprinting, lithographic printed, etc.), and formed via thermoforming or cold forming, then cut to size before insertion.

Curved Film Part/ Second Surface Graphics

This IMD part is the most challenging to manufacture because it combines the complexity of forming the film with the difficulties of injecting resin onto the surface containing the printed graphics. A schematic diagram of the IMD process for producing this type of part would be similar to the one in Fig. 4; however, the graphics are on the second surface (back) of the film.

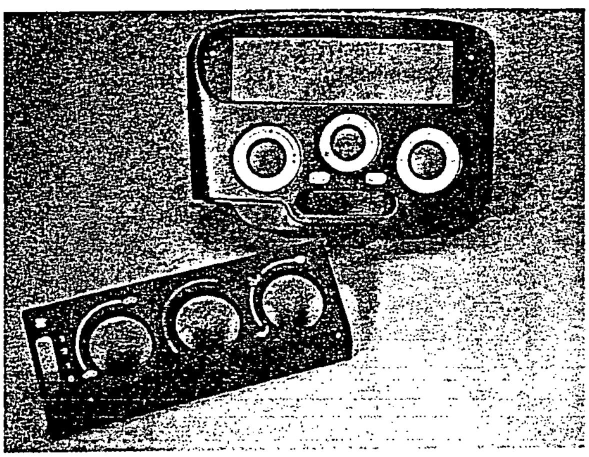
Figure 4: IMD Process: Curved Film Part/First or Second Surface Graphics



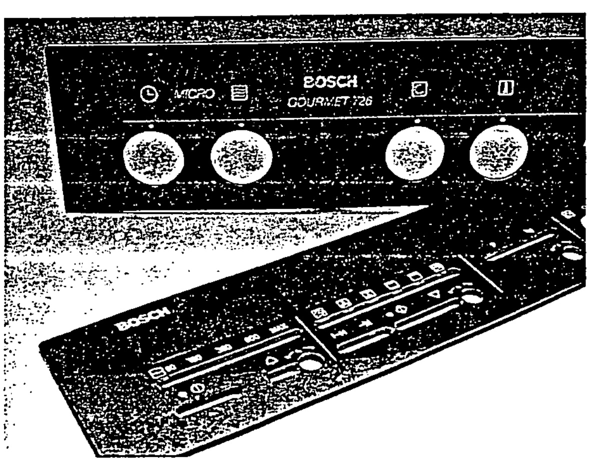
Typical Applications

Telecommunications Part

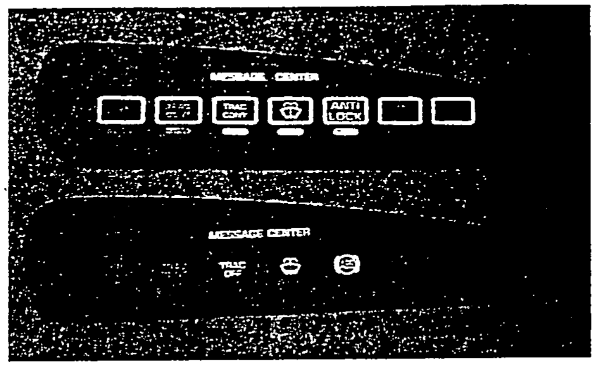
Automotive HVAC Part



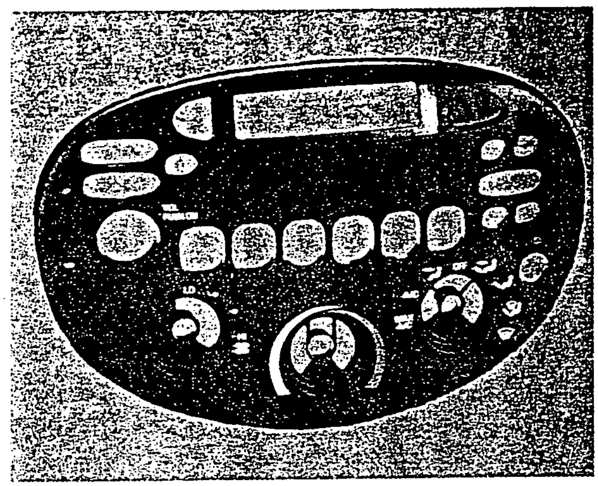
Over door front panel Bosch



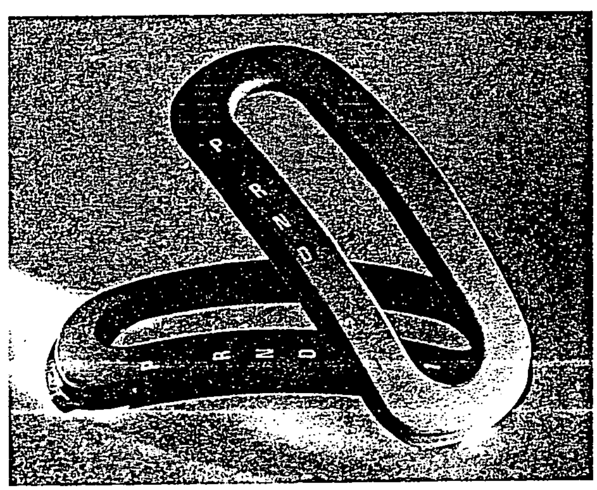
Automotive Message Center Part



Automotive Cluster Part



Automotive PNNDL



Film Selection

Lexan film offers a very good property profile to meet the diverse performance requirements of both screenprinters and other end-users. Lexan film's high quality, clarity, and strength enhance the use of colour, with no loss of depth or vividness in protected, second-surface printing. The film is not only durable, but is also an easy substrate to decorate, offering very good ink adhesion without any pre-treatment. It is available in a wide range of standard and high-performance grades with a variety of surface finishes and textures.

Lexan film offers many processing options, including:

- Selective texturing for mar resistance, low glare and design flexibility.
- Embossing in a variety of configurations for tactile identifications or decoration.
- Dead-front graphics for crisp, clean and highly readable displays.
- Transparent colors for design flexibility and cost-effective production of LED/LCD windows and backlit displays.
- Sharp, high precision die-cutting.
- Deep-draw thermoformable when uncoated.

Uncoated Lexan Films

Uncoated Lexan film is one of the highest quality graphic materials in the industry. Lexan films offer very good optical properties and mechanical benefits.

Uncoated Lexan films are well-suited for use in: automotive, small and large appliances, computer and business equipment, and telecommunications. See the Appendix for a listing of Lexan film graphic grades. Flame-retardant grades are also available.

Lexan High-Performance (HP) Films

A family of high-performance coated films, Lexan HP films offer very good performance and help improve productivity versus costing. Lexan HP films are available in three gloss levels ranging from glass-like (92) to matte (12) in appearance. In addition, Lexan HP films (HP##S and HP##H) are available with two levels of chemical and abrasion resistance to meet a wide range of application requirements. In addition, Lexan HP weatherable (HP##W) films offer long-lasting outdoor performance in a cost-effective, hard-coated film. Lexan HP films should only be used for flat IMD parts.

Table 1: Lexan Film Advantages

Lexan Film Features	Screenprinter Benefits	End-User Benefits
Clarity	Haze resistant, regardless of thickness. Shows true colors in reverse printing regardless of gauge.	Well-suited for LED/LCD windows. Protects second surface printing, even in heavy gauges.
Printability	Easily screenprinted with no surface preparation. Compatible with many UV and conventional solvent-based inks.	Offers numerous possibilities to achieve a variety of graphic effects. Allows intricate graphic designs.
Heat Stability	Allows close-tolerance registration after repeated heat and drying cycles.	Permits close proximity to illumination sources. Very good end-use performance to 270°F (133°C) (continuous use temperature of 185°F (85°C)).
Textures	Abrasion-resistant and anti-reflective textures resist scratching during process and help reduce static-related problems.	Helps to prevent marring and excessive glare.
Flammability	Lexan graphic films have various UV ratings and FR rated (UL 94* V-0 and VTM-0) films are available.	Compliance with UL and other flammability codes.

**This test is not intended to reflect hazards presented by this or any other material under actual fire conditions.*

Film Choice

One of the most important components of the IMD process is the proper selection of film and resin. In most cases, since the film will be decorated, Lexan film is the preferred choice. The choice of the type of Lexan film should be based on the part specifications and the end use application. For IMD parts which require texture or are three-dimensional in design, an uncoated Lexan film (for example: 8010 or 8B35) is recommended. Some typical applications include automotive and telecommunications parts. However, if the part requires chemical or abrasion resistance, then we suggest a coated Lexan film (i.e. HP##S, HP##H, or HP##W). In this case, the part would be flat or two-dimensional only. Some common uses of Lexan HP films are appliance or some telecommunications applications. For in-mold decorated parts, minimum film thicknesses of 0.007" - 0.010" (0.18 – 0.25 mm) are suggested. As always, prototype testing is recommended to ensure performance in the end-use environment.

Typical IMD applications using Lexan films

- Decorative surfaces and labels
- Nameplates
- Back lit driver information centers
- Automotive HVAC/radio bezels
- Appliance appliques
- Lenses for pagers and cellular phones
- Automotive interior buttons

Resin Selection

The other component of an IMD part is the choice of resin. In general, we have found that Lexan films have acceptable in-mold adhesion to either Lexan resins or resins containing polycarbonates, such as Cycoloy or Xenoy resins, as well as some Valox resin grades. GE Plastics has conducted a detailed study of the adhesion of various resins to several types of Lexan, Valox, and Ultem® films. The results of this study are listed in Table 2.

Table 2: Unprinted film adhesion to resin substrates

Resin	Lexan Polished Film	Lexan Textured Film	Lexan HP Film	Valox FR Film	Lexan FR Film
Lexan resin	+	+	+	+	+
Xenoy resin (PC/PBT)	+	+	+	+	+
Valox 325 resin	+	o	+	o	+
Cycoloy resin (ABS/PC)	+	+	o	+	+

Adhesion:
+ = Good (10 lbs./linear inch or better)
0 = Fair (5–10 lbs./linear inch)

Ink Selection

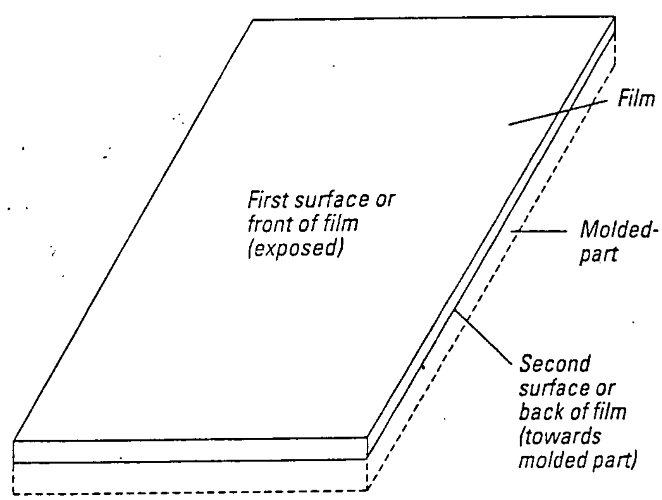
Before an ink selection can be made, one must determine whether the film will be first or second surface printed. This selection is based on the part specifications and the end use application. First surface decoration involves printing on the top or front side of the film. Second surface decoration involves printing on the back or rear surface of the film. Fig. 5 illustrates the distinction between first and second surface printing.

A list of suggested inks for first surface decoration of Lexan films for IMD is listed in the Lexan Film Technical Manual. For second surface decoration, more robust ink systems must be used to provide adequate ink adhesion during the molding process. Evaluations of several inks suggest that there are currently four ink systems which are suitable for second surface IMD parts. These inks are:

- Naz-dar 9600
- Colonial/Coates C-37 series
- Marabuwerke IMD Spezialfarbe 3060
- Nor-Cote (UK) IMD series inks

These inks have the best second surface adhesion and flexibility, as well as improved ink retention near the gate areas. They can be used for first or second surface decoration. Contact addresses are listed in the Appendix.

Figure 5: First vs. Second Surface Decoration



Forming Molds for Films

Prototype molds may be constructed from common materials such as plaster, hard woods, fiberglass, syntactic foam, and silicone. These materials are relatively easy to work with and permit minor modifications.

Recommendations

It is common practice for designers eager to experiment with IMD to cast a silicone forming mold off an existing injection mold. This process is suitable for determining initial feasibility, but note that your formed film samples will not accurately fit the mold cavity due to the combination of material shrinkage and expansion of the casting material. This is especially true in complex three-dimensional parts, and could lead to poor appearance in the in-mold decorated parts. In order to obtain properly fitting film inserts for an existing injection tool, we suggest creating the forming prototype mold from the tool drawings of the injection mold. After establishing feasibility, however, it is suggested that new forming and injection tools be built which are designed specifically for IMD. Production forming molds for use on Lexan film should be constructed of more durable materials such as cast or machined aluminum, steel, or metal-filled epoxy. Conductive molds should be internally heated to a temperature of 250°F (120°C).

Forming Mold Design

The hot formed Lexan part will contract in size once it is removed from the mold and allowed to cool. This shrinkage is predictable and must be considered when calculating the mold dimension, to insure that the finished Lexan part is the proper size. When finished part dimensions are critical, the expansion of the mold at operating temperature must also be considered. Lexan film will typically shrink approximately 0.5%–0.9% (for example: 0.005–0.009 cm per cm) depending on the process-forming conditions. To obtain accurate mold dimensions, the thermal expansion properties of the mold material at an operating temperature of 250°F (120°C) must be subtracted from the Lexan film shrinkage numbers.

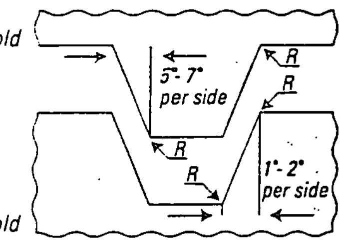
Draft Angles for Vacuum Forming

Draft angles of 5 to 7 degrees are suggested to facilitate part removal on male molds. Female molds require less (1 to 2 degrees). See Fig. 6.

To maximize the part performance and to facilitate proper thickness distribution, all mold corners must be radiused to at least 1x the material thickness. The larger the radii, the better.

Vacuum evacuation areas are required in all sections of the mold that involve part detail. Small vacuum slots created by shimming various mold sections or vacuum holes with a diameter of 0.020" (0.51 mm), drilled every 0.5" (13 mm) are typically sufficient. Molds should not be highly polished because smooth surfaces will trap air. Sand all mold surfaces using 500- or 600-grit emery paper. The small channels created by sanding will provide microscopic passages for air evacuation.

Figure 6



Trimming Tool Design for Films

Die-Cutting

An important aspect of in-mold decoration is the size and consistent dimensions of the printed parts. Typically, two-dimensional Lexan films can be die-cut with either steel rule, matched metal and, to a lesser extent, rotary dies. Lexan film's shear strength of 10,000 psi (70 N/mm²), relatively low in comparison to metals, simplifies and eases tool design and process. Film parts may be cut one at a time or in multiples, depending on press tonnage, working area, and material thickness.

The press tonnage required to die-cut Lexan films can be determined by the following simple formula:

English Units

$$F = \frac{PA}{2{,}000 \text{ lbs/ton}}$$

Metric Units

$$F = \frac{PA}{9{,}000 \text{ N/ton}}$$

F = press tonnage
P = shear strength of Lexan film
A = cross-sectional area

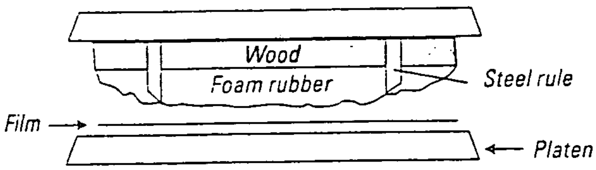
The cross-sectional or shear area can be found by multiplying the total length of the cut by the film thickness.

The most popular and least expensive die-cutting technique is steel rule die. Generally, a 2-point rule (0.028" or 0.71 mm thick) is used to cut Lexan films up to 0.015" (0.38 mm) thick, whereas a 3-point rule (0.042" or 1.1 mm) is used for films greater than 0.015" (0.38 mm).

Steel rule dies are manufactured by three different methods: laser, block, and jig. In general, the laser-cut die will maintain the most accurate dimensional tolerances (+ 0.005" or 0.13 mm), while the jig-cut die will provide the least (+ .015" or 0.78 mm).

In manufacturing a die, a steel rule is fit into a pre-cut pattern in a wooden die board. Stripping rubber on each side of the rule eases part ejection. Generally, stripping rubber should be no more than 1/8" (3.2 mm) above the height of the rule. The figure below illustrates a typical steel rule die.

Figure 7: Steel Rule Die



Depending on rule design, size, shape of part, and thickness of film, the cut parts will be slightly different in size than the rule: holes will be smaller and cut-outs will be larger. Therefore, dies are usually manufactured on either end of the tolerance range. For example, dies to cut holes are made slightly larger than the part size indicated on the print. Lexan films can be successfully "kiss-cut" with platen presses having close tolerance impression adjustment controls. In kiss-cutting, a side bevel is suggested.

Finally, two other methods are used to die-cut Lexan film: matched metal and rotary. Matched metal dies consist of hardened male and female die halves. Matched metal die-cutting operates by shearing the film. It is used to cut intricate patterns, maintain tight dimensional tolerances, and cut thicker films on larger volume production runs (>100,000 parts). Clearance between dies should be less than 0.001" (0.025 mm).

Diemakers for Lexan Film

- Marbach Werkzeugbau GmbH, Heilbronn, Germany — (49) 7131-47010
- Welke and Company, Hildesheim, Germany — (51) 121-264744
- Lazor Form Dies Ltd., Stockport, Cheshire, UK — (44) 161-430-6911
- Preco Industries International, Kent, UK — (44) 1843-848100
- Atlas Steel Rule Die, Elkhart, IN, USA — (219) 295-0050
- Janco, Dover, NY, USA — (603) 742-1581
- Display Pack, Grand Rapids, MI, USA — (616) 451-3061
- Edward D. Segen & Co., Inc., Milford, CT, USA — (203) 877-8203
- The Stan-Allen Company, Ludlow, MA, USA — (413) 589-9961
- DV Die Cutting, Inc., Danvers, MA, USA — (508) 777-0300

Injection Molding Tool Design

Concurrent design of the injection and forming tool is essential to ensure that the insert fits correctly.

If the film preform is too large relative to the cavity, you can get wrinkles in the film. If the film is too small, you can get stretching and yielding of the film. Shrinkage calculations are an important step in the part design. To determine which size thermo-forming tool is necessary to form the film that properly fits in the injection mold, you must account for the following shrinkage factors:

- Thermal expansion of the thermo-forming tool
- Shrinkage of the formed film sample
- Thermal expansion of the injection tool
- Used shrinkage factor of the resin

The film sample should not be in the injection tool long enough to expand significantly.

Draft

Include draft on all surfaces in the die's or cam's line of draw. Normally, the greater the draft angle, the easier it is to eject the part from the mold. The design of the in-mold decorated part is highly dependent upon the formability of the film. Male forming tools typically do not permit the deep draws and small draft angles found in injection molded parts. Draft angles less than 3–5° may cause forming issues. The formed insert should fit as snugly as possible in the cavity, so it is necessary to constrain the design of the injection tool by that of the forming tool. Keep in mind that it is much easier and less expensive to change a forming tool than an injection mold.

Part Geometry Considerations

Part design will greatly influence the manufacturability of an IMD part. Therefore, it is suggested that the designer minimize the following:

- Deep draws
- Recesses
- Sharp corners or edges
- Severe undercuts
- Film wraparound
- Abrupt wall thickness transitions

Parts with these features lead to wrinkling, thinning, and loss of colour in the decorated film. In addition, unequal resin flow during molding (race tracking) can cause wrinkles in the film, so maintaining a constant wall thickness whenever possible is suggested.

Injection Molding Tooling

Mold Materials

Choose a mold steel with a high hardness and wear resistance for parting line durability. Any film that becomes caught in your parting line could damage your tool if you have not designed the tool to accommodate it. It is common practice to use P-20 steel in the majority of the tool, and to use steel with a hardness of Rc 55 or higher in the parting line area. Common mold materials

are listed in Table 3 below. Other standard mold building practices apply to IMD. Therefore, it is recommended that you:

- Use abrasive-resistant steel if you plan to run glass or mineral-filled resins.
- Construct moving steel components with different alloying and hardness from the rest of the mold to prevent galling and high adhesive wear.
- Keep in mind the finish desired. Polish cores and cavities to a 400 or higher stone finish to provide a smooth, maximum DOI finish. Textured films are available, and textures put into the mold work very well, also.

Prototype Tooling Soft, lower-cost molds can serve a valuable function by providing pre-production parts for marketing studies, manufacturing assembly requirements, and dimensional capabilities. They also give the designer an opportunity to evaluate some unusual functions. Important molding information such as how to locate the film and what gate locations are best for your IMD application can also be gained through prototyping. This information can be later translated to the production mold.

All casting and plating processes require a model that will be faithfully reproduced. The quality and durability of prototype tooling depend on the process. Some molds may produce fewer than 100 pieces, whereas others function for many thousands of pieces. The cost and timing of the project may be the deciding factor as to which method used.

Some common methods for producing prototype injection molding tools are as follows:

Conventional Machining Practices

- Steel (unhardened)
- Aluminium
- Brass

Casting Process

- Kirksite (a metal casting material)
- Aluminium
- Plastics, epoxies

Liquid Plating Process

- Intricate shells can be nickel plated on a master. These are later backed up and inserted into a mold frame.

Flame Spraying

- Flame spray metals can quickly produce a 1/8" (3.18 mm) thick shell which is further backed up and placed into a regular frame. A variety of metals which come in wire form can be utilized in the process.

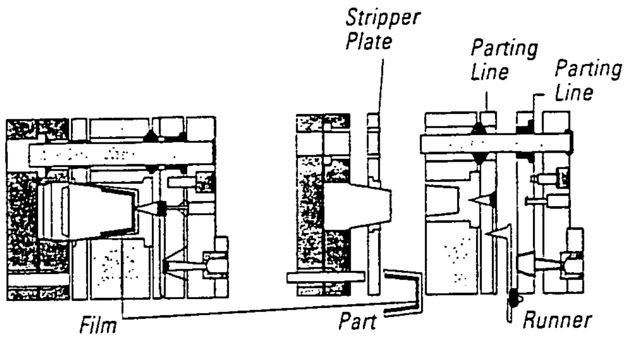
Ejection Methods Part ejection can be accomplished in several ways. The most common method for part ejection is the use of stripper plates or bars. The large contact area for part ejection means there is less chance for induced stress in the molded part. This results in better dimensional integrity and reduced part damage.

Table 3: Commonly Used Types of Steel Injection Molds

USA Code	DIN Code	Applications	Remarks	Hardness - HRC
M-2	1-3343	Core pins, gate inserts.	Extreme hardness, abrasive resistance with good toughness.	62-64
	1-2162	Cavity, core or inserts.	Surface hardening.	62
A6	1-2764	Cavity, core or inserts.	Surface hardening. High polish possible. Compressive strength.	56-62
D-2	1-2379	Gates and cavities. Glass or mineral-filled materials.	High hardness. Good abrasion resistance.	57-59
A8	1-2606	Slides, lifters, cams.	Very good wear resistance.	56-58
A-2	1-2767	Cavity, core or inserts.	Through hardening. High polish possible. For high pressure.	55-57
SS 420	1-2083	Cavity, core or inserts.	Corrosion resistance. Thorough hardening.	52-54
	1-2343	Hot runner parts.	For high temperature fluctuations.	50-52
	1-1730	General purpose. Bolster. Ejector plates.	Relatively soft. Hardening not recommended.	47-56
P20	1-2311	Bolster plate, cavity, core and inserts.	Pre-hardened. Good polish. Applicable for textures. Used for large molds.	45-48
H-13	1-2312	Bolster plate, cavity, core and inserts.	Pre-hardened. Good polish. Less applicable for textures. Used for large molds.	45-48

An example of a three-plate tool that implements a stripper plate for part ejection is shown in Fig. 8.

Figure 8: Three-Plate Tool Closed and Three Plate Tool Open for Overmolding with Film on Core



Knock-out pins are a common method of part ejection. For best results, keep in mind these general considerations: For optimum results it is important to use an ample number of knock-out pins. Design these pins with sufficient area to avoid compressing the resin surface and affecting the film on the show surface. Also, locate the pins so they do not induce stress in the part. The use of sleeve ejectors for part bosses is suggested.

Avoid external mold release agents when performing IMD, since the mold release may deposit onto the film and affect its appearance. If necessary, the use of a tool plating process can aid in part ejection.

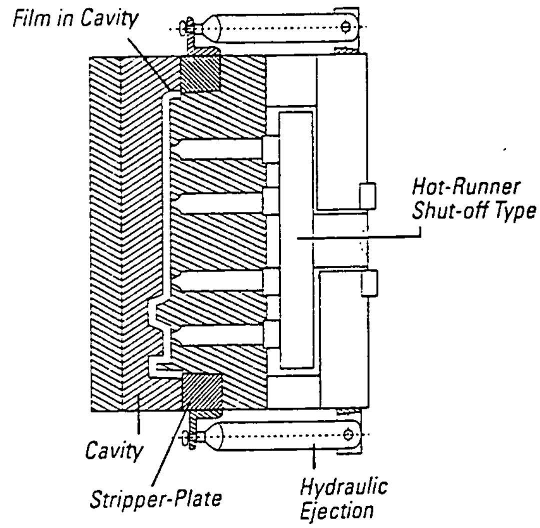
Special Ejection and Injection Considerations

IMD requires special consideration for the ejection of the finished part. Since the object is to decorate the surface of the part, it is essential to keep the decorated surface free from any moving parts of the mold that could potentially mar it. Two methods, reverse ejection and reverse injection, are commonly used to accomplish this.

Reverse Ejection

Reverse ejection is appropriate when using hot manifold systems or direct sprue gates with an IMD application. With this system, both injection and ejection occur on the fixed side of the mold, using a hydraulic or air ejection system as shown in Fig. 9. It is possible to tie the hydraulics into the injection molding machine electrically so that you can still run in automatic mode. For large parts, needle shut-off nozzles with sequential controls are used. You can expect an additional 10-25% cost for constructing your mold due to the added complexity of tool design and machining.

Figure 9: Back Side Mold-ins with Film in Cavity



Reverse injection (see Fig. 10 and Fig. 11) is accomplished by shooting resin from the fixed side of the mold to the movable side and filling from the back side of the part. This allows you to use standard ejection from the tool if needed. However, the sprue and runner system must be extended beyond the parting line into the movable side of the mold to allow the resin to flow to the back side of the film consistently. Reverse injection works well with submarine gates into ribs or ejectors and cashew gates into wall sections. This can be done in combination with hotrunners.

Figure 10: Tunnel Gate

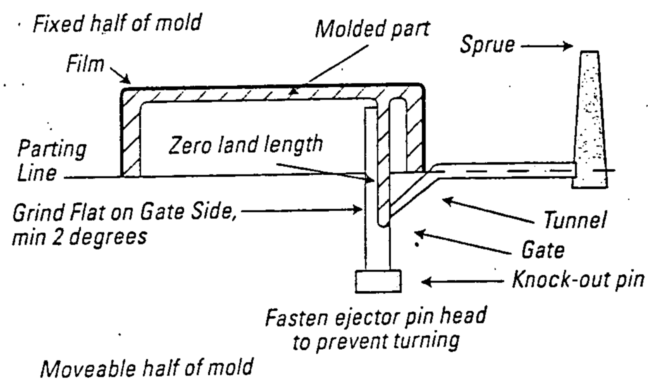
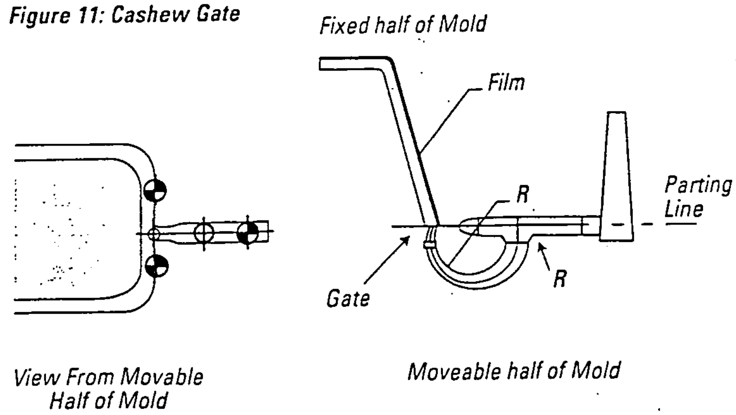


Figure 11: Cashew Gate



Sprues and Runners

IMD does not typically require special sprues or runner systems. Follow the design guidelines for the resin being used (Injection Molding Design Guides are available by contacting GE Plastics Product Support at (800) 845-0600 or via the Internet at http://www.ge.com/plastics/gp3.html).

Hot Sprues

Hot sprues are commonly used in single cavity tools. Some IMD applications can be accomplished through processing with most types of heated sprue bushings. However, it is suggested that a cold tip be incorporated to insulate the film from the hot sprue. Without the cold tip, there is a risk of melting the film and causing severe washout even in first surface IMD parts. For other ideas, follow the suggestions set forth in the injection molding guide of the resin being used.

Hot Runners

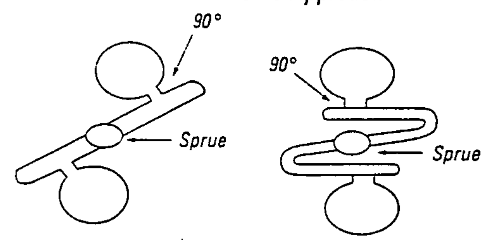
Hot runner or hot manifold systems are common in multi-cavity tools and large parts that require multiple drops. Hot runner systems have been used successfully in IMD applications. Hot runner manifolds are available from several suppliers. As with heated sprues, any nozzle that drops directly onto an area where film will be should have cold tips for insulating the film.

Gating

The basic considerations in gating are part design, flow, end-use requirements, and location of in-mold graphics. The standard guidelines of traditional gating apply to IMD, along with some extra considerations:

- Use one gate whenever possible to minimize the potential of wrinkling the film. Large parts that require multiple gates should include gates positioned close enough together to reduce pressure loss. Use sequential gating to help prevent folding of the film at weld lines.
- Keep gate land lengths as short as possible.
- An impinging gate can ensure that the incoming flow is directed against the cavity wall or core to avoid jetting.
- To avoid trapped gas that can burn and rupture film, the resin flow from the gates should direct air toward the vents. When the film is in the mold, two pockets of air (one on each side of the film) will usually form and will need to be vented. Venting can be accomplished through knock outs, cores, and parting lines. Full perimeter venting is suggested when possible. To avoid air trapped by larger parts between film and cavity, a full closed box around the ejection system in combination with vacuum is recommended.
- Locate gates to provide flow from thick to thin sections and to minimize weld lines. Also, locate the gates away from end-use impact.
- Locate gates at right angles to the runner to minimize jetting, splay, and gate blush. This is illustrated below.

Figure 12: Indirect Runner to Gate Approach



- The film should extend over the gate area to facilitate consistent resin flow to the correct side of the film. This is shown here for edge, flash and fan gates.

Figure 13: Edge Gate

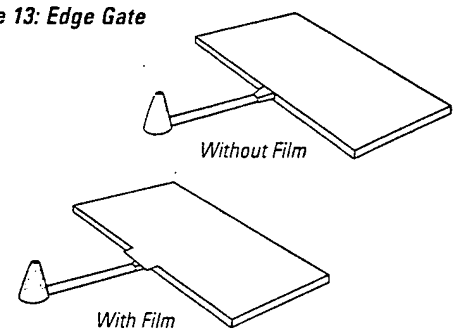


Figure 14: Flash Gate

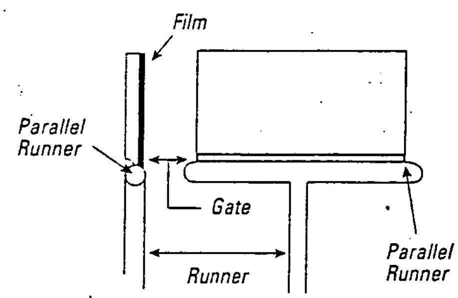
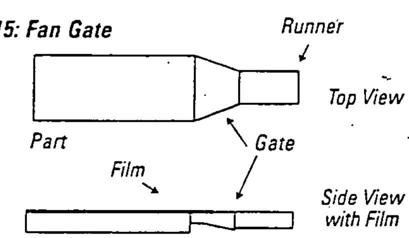


Figure 15: Fan Gate



- Flow restrictions near a gate area can increase the potential for washout due to increased shear. If bosses, core shutoffs, etc., are needed near a gate, use rounded features or corners to reduce shear. An example is shown below in Fig. 18.

Graphic Placement

Whenever possible, graphics should be positioned away from gate areas. In general, the washout distance will depend on wall thickness, ink choice, resin choice, and gate type. Typical applications require a minimum distance between the gate and the graphics of 0.25 inches (7 mm).

Gating Type for Second Surface Printing

The following table lists some typical gates used in injection molding and their application to second surface IMD. Whereas most gate types have been used successfully in first surface IMD applications, second surface IMD applications require special ink and gate considerations.

Table 4

Gate Type	Second Surface Issues
Sub/Tunnel Into Rib	Works well. Graphics can be directly over rib.
Fan	Graphics 0-2 mm from gate or extend into gate.
Sub/Tunnel Into K.O. Pin	Localized wash out. Graphics 5-7 mm from gate.
Cashew	Localized washout. Graphics 7-10 mm from gate.
Tab	Direct resin perpendicular to wall away from film. Graphics 5-7 mm from gate.
Direct Sprue	Keep graphics 10-15 mm away.

Gating Solutions

Two gating techniques that have worked well with second surface printed parts are pictured below. The first method (Fig. 16) involves gating into an area that will have washout, but will be trimmed off later. The second (Fig. 18 & 19) shows the initial direction of flow that can minimize washout at the gate.

Figure 16: Gate Below P-Line

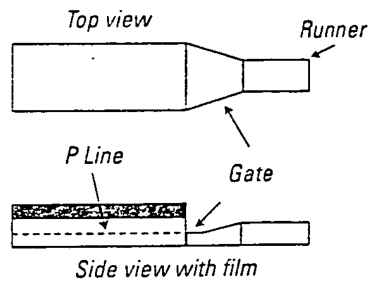


Figure 17: Cavity for Film

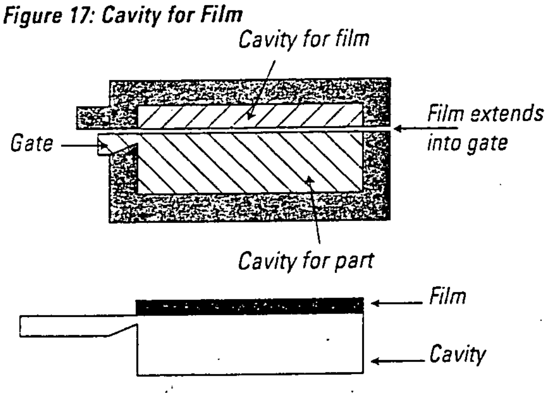
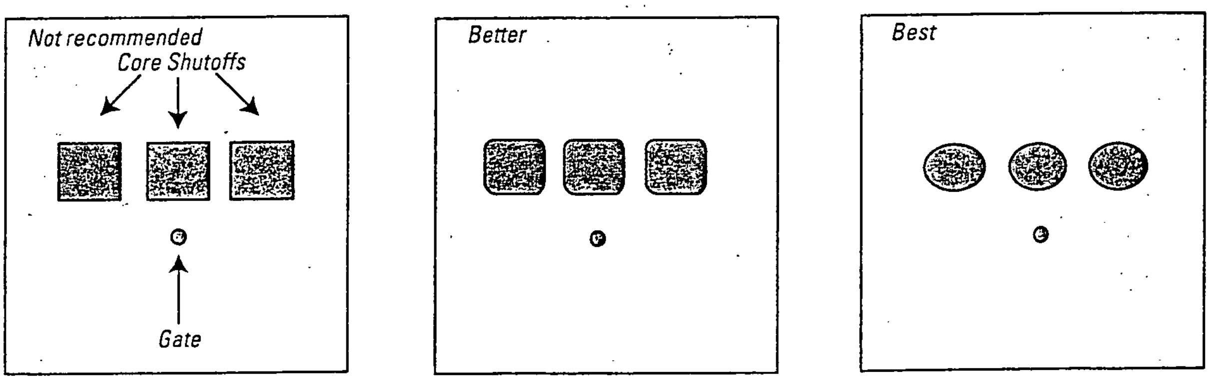


Figure 18: Flow Restriction Example

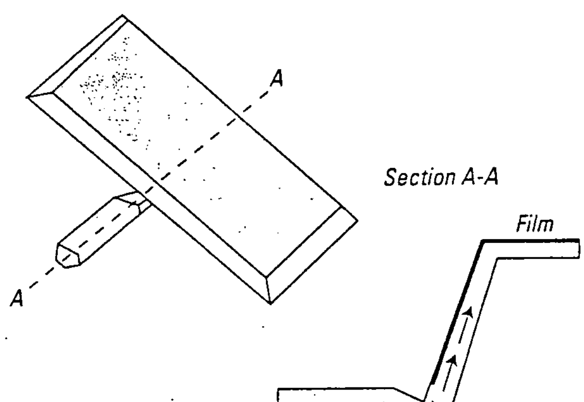


Things that affect adhesion:

- Drying the film
  120°C for 40 (min/cm) x thickness (mm)
  Example: a 0.5 mm film is dried for 20 minutes
- Processing conditions
  (Cold molds and cold melts can cause problems)
- Contamination

Gate Type	Second Surface Issues	Second Surface Washout Ranking
Sub/Tunnel	Sub gating into a rib has produced parts with no washout, even with graphics directly above the rib.	Best
Into a Rib	Standard rib design was used. This can be an ideal gate for use in reverse injected parts.	
Fan	This gate effectively distributes shear across a large area of the part, thereby minimizing washout. Graphics can be designed very close to the gate. It is a strong candidate for flat parts including lenses.	
Sub/Tunnel into a Knock-out Pin	Sub gating into ejector pins has caused localized washout, with all inks having good adhesion. This is a good gate to use in reverse injected parts. Design graphics away from this gate.	
Edge	This gate can be very effective when the resin is directed against the cavity wall opposite the film. It is very useful in standard tool designs with cold runner systems.	
Cashew	This gate can be worse than sub gating into a knock-out because it imparts high localized shear against the film. It is a good choice in reverse injected applications. Design graphics away from this gate.	
Tab	Gating into a tab which was parallel to a flat part resulted in a large degree of washout. A tab which is perpendicular to the wall of a part should yield better results if the resin is directed to the cavity wall opposite that of the film.	
Direct Sprue	No known applications have successfully used this gate without getting washout. It may still be a viable option if you design your graphics so they are not near the gate. Sink is a common problem with this gate even in first surface applications.	Worst

Figure 19: Using Flow Direction to Minimize Washout



Flow directed against far wall, not against film

Securing Film

One aspect of tool design that cannot be overlooked is how to hold the film in place. In order to ensure consistent uniform part coverage, films must be placed and held in the same position within the mold during each cycle. Several options exist which can be used on either the core or cavity side of the tool, depending on the side used for ejection:

- Vacuum (holes or porous metal inserts)
- Static Charge
- Locator Pins
- Part Geometry/Friction

Screenprinting

Screenprinting is a common and convenient technique used in the industry to produce graphics on film substrates. There are many excellent reference materials on the screenprinting process and many companies skilled in this trade. A diagram of the typical screen printing process is shown below (Fig. 20). Lexan film's clarity at any gauge makes it a very good candidate for graphic overlays and displays. In addition, most inks adhere well to Lexan film without pre-treatment or print coating of any kind. Screenprinting is essentially a stencil printing process which has progressed over the years. Now, screens and graphics can be generated via computers and various software packages.

Screenprinting has enjoyed wide industrial use for many years due to its ability to accurately control ink thickness. This ability has made this process extremely useful in decorating many different types of plastic substrates.

Screenprinting involves the preparation of screen or stencil which is bonded to a fine weave fabric tensioned in a rigid frame. Frames for screens can be made of either wood or metal. Today, metal is more commonly used. It is important that the frame be dimensionally stable and able to withstand handling during the printing process. Screen fabrics are generally made from polyester, metallized polyester, nylon, and stainless steel. The most common screen material today is polyester. This polyester fabric is tightly woven under precise control using dimensionally exact filaments. There are a number of variables that affect ink deposit screenprinting: thread diameter, squeegee angle, squeegee hardness, and emulsion thickness. *Higher mesh screens are suggested for formed IMD applications.*

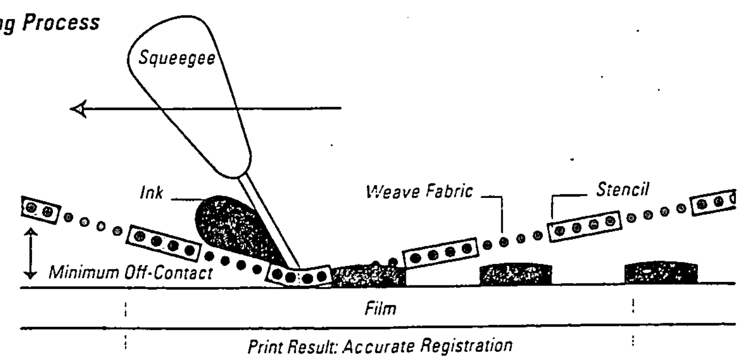
Screens are usually prepared by the use of photo-image stencils. The photo-image process begins with the application of photosensitive emulsions or films to the screens. The sensitized screen is then exposed to light through a positive image of the artwork, developed and dried. The portion of the screen which is exposed to the photosensitive light is hardened and made insoluble, while the image is exposed and the material above remains soluble. The image is developed by washing away the soluble material.

The basic screenprinting process involves the use of a flat bed where the substrate is held by vacuum during printing. A frame holder positions the screen and holds it secure both vertically and horizontally, during the printing process. With the screen lowered over the substrate bed and held at the off contact distance by the press, the squeegee carrier moves the blade across the screen at a preset speed, pressure, stroke and angle. Some machines will raise one end of the screen frame in order to facilitate the break away of the screen from the substrate during the printing process. Most commercial screenprinting equipment is semiautomatic, and requires loading and unloading the substrate while the printing process proceeds automatically. There are also fully automatic screenprinting presses that do not require operator intervention.

It is important to register the artwork during a screenprinting operation. This is normally accomplished by locking the frame into a holder that aligns the frame using pins or holders. The pin alignment method is generally preferred, because the artwork can be aligned along with the screen frame. Alignment of the substrate with the print image is done through the use of edge guides, mechanical stops, or automatic devices. The first color is aligned by this method and subsequent colors are aligned through the use of targets or gauge marks which are printed alongside the artwork.

Once the ink is printed, it must be either dried or cured, depending on the ink technology used. If the ink is solvent or water based, then a gas-fired or electric dryer can be used to dry the ink. When printing on plastic films, it is important to control the temperature and dwell time in the oven to avoid distorting the film. If a solvent ink is used, it is important to have an oven with good air flow to dissipate the fumes. It is also possible to use an infrared dryer to dry some ink types, but particular attention must be paid to the temperature control of the system. If the ink is UV curable, many commercial units are available to cure these reactive ink types. This ink technology is rapidly growing due to the low capital process investment and the fast cure times of this technology for plastic substrates. *Specific suggestions for processing Nor-Cote's IMD Series inks are included in the Appendix.*

Figure 20: Mechanics of the Screenprinting Process



Ink Preparation
- Mix thoroughly
- Avoid particulate contamination

Mesh
- High mesh screens best for formed apps.
- Plain weaves give best results

Stencil
- Photo-imaging used
- Emulsion system must be compatible with ink

Squeegee
- Sharp, 80-90 Durometer
- Polyurethane preferred

Curing/Drying

Solvent Inks
- Hot air oven
- 30-45 secs. dry time
- All solvents must be driven off prior to molding
- Can take 3 to 4 days of rack drying

UV Inks
- Two 200 watt/inch or one 300 watt/inch focused UV Lamp(s)
- 40-80 ft./min. belt speed

Forming IMD Films

There are two basic techniques to form 3-D IMD parts: thermoforming and cold forming. The method that the molder and printer selects will depend on the shape and design of the part.

If the part has 35 mm draw depth, then thermoforming is suggested. Parts with detailed alphanumeric graphics should be formed with cold forming or variations of the cold forming process.

Cold Forming

Cold forming is a good process for forming parts containing alphanumeric graphics with draw depths up to 35 mm. The cold forming process is different in two distinct ways. First, it is an ambient forming process. Second, the typical die-set is eliminated in favor of a hydraulic fluid cell assembly that has a diaphragm face. Differences in these processes are shown in Fig. 21 and 22. Cold forming has a number of advantages over conventional forming techniques, including:

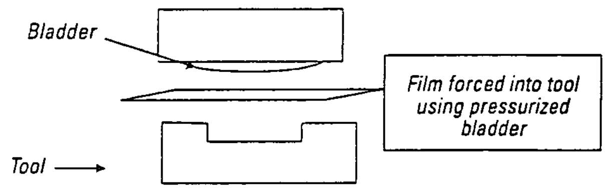
- High yields with image accurate locater registration
- Reduced tooling costs
- Reduced distortion to the graphics
- Reduced thermal damage to inks or film substrates
- Longer life for the tooling
- Predrying not necessary

Two possible cold formers with IMD experience using GE Lexan film are:

EMME 2 s.r.l.
Strada Nationale, 67
10020 Cambiano (TO) Italy
Phone: (39) 11 - 9442144
Fax (39) 11 - 9441457

Hy-Tech Forming Systems Inc.
2425 West Desert Cove
Phoenix, AZ 85029
602-944-1526

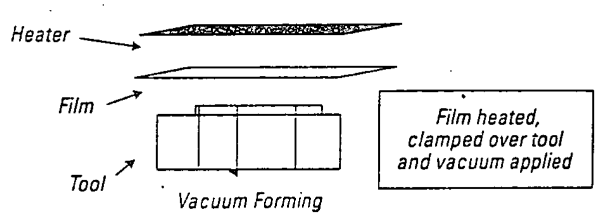
Figure 21: Cold Forming 3-D Parts



Thermoforming

Thermoforming is a good method for producing three-dimensional shapes when using GE Lexan film. Lexan film's high melt strength makes this material a strong candidate for forming. Lexan film can be easily thermoformed with sharp detail on forming equipment that incorporates top and bottom heaters, or that allows the heating of the film directly over the mold using a rapid transfer system to move the film from the heating station to the forming station. This rapid transfer of the film from the heating station to the forming station or direct overhead heating is necessary because the Lexan film cools quickly and sets up at a higher temperature than most other thermoplastic materials.

Figure 22: Thermoforming 3-D Parts



Drying

Lexan sheeted film must be dried prior to nearly all thermoforming operations. The moisture content in the film can cause bubbling and loss of detail. For drying, you can use a hot air circulating oven set at 250°F (120°C). The film should be racked vertically or horizontally in the oven with a separation between the sheets of approximately 1 inch (25 mm). After the film has been dried it should be usable for up to 4 hours without redrying. The drying time for Lexan film is dependent upon thickness: 0.010 inch (0.25 mm) for 15 minutes, 0.015 – 0.020 inch (0.38 – 0.51 mm) for 20 minutes

and 0.025 – 0.030 inch (0.64 – 0.76 mm) for 30 minutes. Web-fed forming of Lexan film in thicknesses below 0.030 inch (0.76 mm) can be formed without predrying, providing the part configuration and draw ratio are not too severe and heating of the Lexan film is done gradually to reduce the chance of moisture bubbling. The length of the oven should be at least four times the size of the forming station. (Example: a 24" x 24" (61 x 61 cm) forming table will require a 96" (244 cm) long tunnel oven.) Top and bottom heating is suggested.

Forming Temperatures The normal processing temperature range for Lexan film is between 350-400°F (177-205°C). The optimum forming temperature will vary depending on the part design and depth of draw.

Injection Molding for IMD

Injection Molding Equipment IMD can be done in standard injection molding machines.

Injection Molding Machine Selection When determining the size of equipment to be used for molding with IMD, total shot weight and total projected area of the part are still the two deciding factors to be considered. Optimum results are typically obtained when the total shot weight (all cavities plus runners and sprues) is equal to 30% to 80% of the machine capacity.

Very small shots in a large barrel machine may create unnecessarily long resin residence times that may lead to resin degradation.

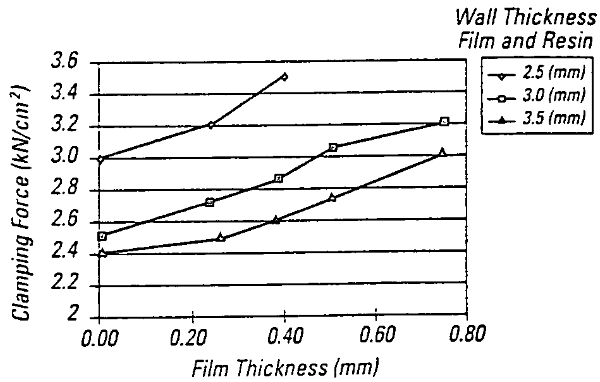
In cases where part geometry requires molding at the high end of the temperature range for a given material, reduced residence time is required to reduce the possibility of material limit degradation. Therefore, for higher temperature molding requirements, it is suggested that the minimum shot size be greater than 60% of the machine capacity. Three to five tons of clamp force should be provided for each square inch of projected area to avoid flashing of the part. Wall thickness, flow length and molding conditions will typically determine the actual tonnage required. The graph on the following page shows the effect that film and part thickness have on clamp tonnage.

Barrel Selection and Scr w Design Considerations

Most conventional barrels and screw designs used for molding engineering resins are compatible with IMD.

Nozzle Design Use a nozzle design that is compatible with the engineering resin you are molding. Consult the GE Plastics injection molding guide for that particular resin for suggestions on nozzle design.

Graph 1: Influence of Film and Part/Thickness on Clamping Force



Drying Most thermoplastics absorb atmospheric moisture which, at normal processing temperatures, can cause degradation of the polymers with a consequent lowering of property levels, particularly impact strength. Therefore, it is suggested that the resin be dried prior to molding as per the guidelines established for that resin. Contact the Sales Service centers of GE Plastics at the following numbers if you have questions on how to dry the resin:

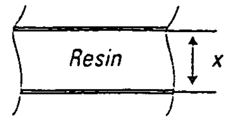
Austria	*(43) 2622-3900*	*Netherlands*	*(31) 164-292742*
France	*(33) 1-6079-6900*	*Spain*	*(34) 3-488-0318*
Germany	*(49) 6142-6010*	*UK*	*(44) 161-905-5001*
Italy	*(39) 2-61-8341*	*USA*	*(800) 437-5278*

Lexan film does not require drying prior to the injection molding process.

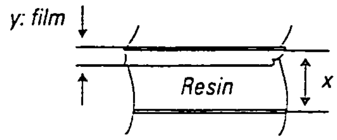
Mold Filling Pressure Molding parameters are related to part thickness, part geometry and the chosen gate system. Expect pressures to rise with film inserted into the mold cavity. Experimental data obtained using a 0.010 inch (0.25 mm) thick sample of film in a 12" x 10" x 0.1" (400 x 250 x 2,5 mm) plaque tool suggest an increase of <5% in injection pressure to fill the part using a direct rate in the center of the part (e.g. 250 mm flowlength). The following three scenarios (Fig. 22) and the graph for situation B sum up the changes in injection pressure that can be expected when using in-mold films.

Figure 22: Filling Pressures

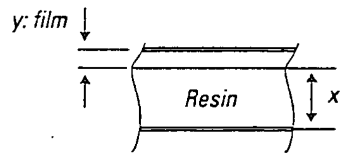
A. Without film: Injection pressure is normal



B. Film placed in cavity of A: Injection pressure increases

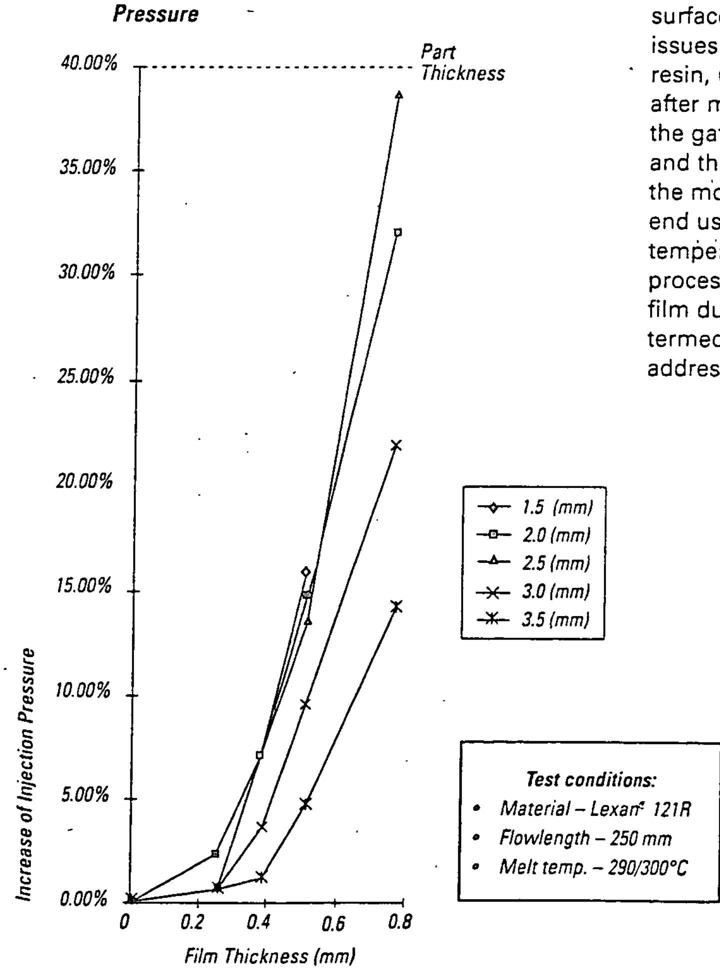


C. Thickness in cavity for A increased to accommodate film: Injection pressure decreases



Low injection speed reduces shear rates on the film, but may increase the chance of the resin freezing off prior to completely filling the mold. However, because the film acts as an insulator, freezing off of the resin is less likely to occur.

Graph 2: Influence of Film and Part Thickness on Injection Pressure



Cushion

The use of a small cushion [1/8 inch (3.18 mm) suggested] allows for film and machine variations. Remember that your shot weight will be less with the film in place. After filling the part without using film, either remove some of the shot size or adjust your transfer point to compensate for the volume of the film inserted. This can help prevent flashing the part.

Mold Temperature

Mold temperatures are important in determining final part finish and molded-in stress levels. Cold molds are more difficult to fill, necessitating high injection pressure and melt temperature. Heated molds generally produce a part with a better finish and lower molded-in stress. Films used in IMD act as an insulator between the resin and the mold. As a result, uneven cooling may occur due to the reduction of heat transfer from the resin through the film. This causes molded-in stress and increases the potential of warping. It is possible to adapt temperature in the mold to help compensate for the warping.

Special considerations for second surface in-mold-decoration

When injecting resin against an ink, as in second surface IMD, new issues arise. The three main issues are: (1) adhesion between the ink and the resin, (2) adhesion between the ink and the film after molding, and (3) washing away of the ink near the gate. If there is poor adhesion between the ink and the resin, the printed film can pull away from the molded part during temperature cycling and in end use. If the ink system cannot handle the temperatures and pressures of the molding process, the resin melt can "wash" the ink off the film during molding. This phenomenon has been termed "washout". Below are some suggestions for addressing these two second surface IMD issues.

Table 6: IMD Inks Which Are Compatible with Lexan Film

Manufacturer	Product(s)
Coates/Colonial/Color Mix Printing Inks, Inc. 180 E. Union Avenue East Rutherford, NJ 07073 (201) 933-6100	C-37 Series
Naz-Dar 8501 Hedge Lane Terrace Shawnee, KS 66227 (913) 422-1888	9600 Series
Marabuwerke GmbH & co. Asperger Strasse 4 71732 Tamm Deutschland (49) 7141-691-0	IMD Spezialfarbe 3060
Nor-Cote UK, Ltd. Unit 7, Warrior Park, Eagle Close Chandlers Ford Ind. Estate Eastleigh, Hampshire United Kingdom S053 4NF (44) 1703-270542	IMD Series

Marabu IMD 3060 series manufacturer's guidelines

Preparing the ink
The ink should be thoroughly mixed prior to use. It should be thinned 10-15% to give the correct printing viscosity.

Mesh
Mesh counts of 230 (90) to 355 (140) plain weave polyester can be used, but 305 (120) gives the best results. Screen tension should be greater than 16N/cm.

Stencil
Any solvent-resistant photo emulsion or film can be used.

Squeegee
No specific recommendations.

Curing
Can be cured with hot air drying, oven drying or with infrared, but must pass a cooling zone prior to stacking. It is important to remove all solvents before stacking and molding operations; once stacked, the solvents cannot easily escape.

Tips for solvent based inks

Removal of the solvent from the printed ink is key to obtaining a good result. Although thicker ink layers give better opacity, this can lead to solvent entrapment and poor results.

To achieve the required opacity it may be better to increase the number of layers rather than the thickness of the layer.

Be aware that if films are stacked before all solvent is removed, this solvent will remain and cause failure in the process.

Nor-Cote IMD ink series manufacturer's guidelines*

Printer recommendations

Preparing the ink
The ink should be thoroughly mixed prior to use. Ink is supplied print ready for most applications.

Mesh
Mesh counts of 305 (120) to 355 (140) plain weaves tend to give the best results, although some twill weaves can be used as well. Tension should be in the 16-20 N/cm range on a rigid frame.

Stencil
Most emulsion systems can be used. Smoothly applied direct emulsions or thin capillary films (15-25 microns) that are UV-ink compatible will provide good results.

Squeegee
A molded squeegee will give better chemical resistance. A sharp 80-90 durometer polyurethane is preferred.

Curing equipment & parameters
IMD inks work best when exposed to adequate UV energy levels. Typically, a UV curing unit with one 300-watt-per-inch (120 w/cm) focused lamp or two 200-watt-per-inch (80 w/cm) lamps should be used. Belt speeds of 40-80 feet per minute (15-30 m/min) are normal; curing speed will depend on the opacity of the ink and the ink film thickness.

Tips for UV curable systems

Thicker ink layers give better opacity but are more difficult to cure due to penetration of the UV light through the film. Poor cure normally results in poor adhesion of the ink layer. Overcure of the ink layer can cause "surface lock" of the ink or surrounding uncoated film. Surface lock prevents subsequent layers of ink or the injection molded resin from adhering. To obtain the ultimate cure, the 80% rule is recommended, i.e. test cure by carrying out cross hatch adhesion tests, increase track speed until marginal failure is obtained, then reduce the track speed to 80% of that value.

UV lamps produce infrared as well as ultraviolet, and thin films can therefore be distorted by the heat build up, dichloric reflectors which minimize reflection of I.R. (infrared) aid in controlling substrate temperatures without effecting U.V. energy levels.

* Received from Nor-Cote, February 1997

Table 7: Lexan Graphic Film Product Offering

Category	Designation	Description	Guage inches	Guage μ	Roll Widths inches	Roll Widths mm
Graphic Arts Polished	8010	Polished/Polished	0.005 – 0.030	125 - 750	36 and 48 60 only	915 and 1220 1525 only
Textured	8A13	Polished/Matt	0.005 – 0.025	125 – 625	36 and 48	915 and 1220
	8A35	Polished/Velvet	0.005 – 0.030	125 – 750	36 and 48	915 and 1220
	8B35F	Fine Matt/Velvet	0.007 0.010 – 0.020	175 250 – 500	36 only 36 and 48	915 only 915 and 1220
	8B35	Matt/Velvet	0.003 0.005 – 0.020	75 125 – 500	36, 48 and 55 36, 48 and 60	915, 1220 and 1400 915, 1220 and 1525
	8B36	Matt/Suede	0.010 – 0.020	250 – 500	36 and 48	915 and 1220
	8A13F	Fine Matt/Polish	0.010 – 0.030	250 – 750	36 and 48	915 and 1220
	8A73	Matt/Polish	0.010 – 0.020	250 – 500	36 and 48	915 and 1220
					36 and 48	915 and 1220
Coated (S) Standard, first surface printable	HP92S, H, W, WP	Polished/Polished	0.007 – 0.030	175 – 750	48 Double Rolls Only (All)	1220 Double Rolls Only (All)
(H) Hard, maximum chemical and abrasion resistance	HP60S, H HP40S, H HP12S, H, W	Matt/Polished Matt/Polished	0.007 – 0.030 0.007 – 0.030	175 – 750 175 – 750		
(W) Weatherable						
(WP) Weatherable, first surface printable						